Relationship between stomatal behavior and characteristics of photosynthesis and transpiration of *Adenophora lobophylla* and *A. potaninii* at different altitudes[1]

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Abstract The photosynthesis and transpiration characteristics of *Adenophora lobophylla* and *A. potaninii*, as well as stomatal behavior such as stomatal size, stomatal density, stomatal open and stomatal conductivity were measured at different altitudes. The relationship between the photosynthesis and transpiration characteristics and the stomatal behavior was analysed by correlation coefficient and path coefficient analysis with altitude changes. The results showed that the influences of stomatal behavior were not evident on the photosynthesis and transpiration characteristics of *A. Lobophylla*, but evident on that of *A. potaninii*.

Key words: *Adenophora lobophylla*, *Adenophora potaninii*, Stomatal behavior, Photosynthesis, Transpiration

Introduction

Adenophora lobophylla and *Adenophora potaninii* are perennial herb under the jurisdiction of *Adenophora* of Campanulaceae. *A. lobophylla* population distributes in the northwest area of Jinchuan County, in northwest Sichuan Province, at altitudes from 2 000 m to 3 400 m, and the distribution area is estimated less 500 km^2 . *A. potaninii* population is an extensive species which distributes not only in the northwest area of Sichuan Province but also in Qinghai, Gansu, Shanxi, Ningxia and Shanxi. In recent years, the studies on endangered mechanism for *A. lobophylla* have been reported, but the report on stomatal physiology ecology has not been found (Zhang 1998; Zu and Yan 1998). From the point of view of stomatal physiology ecology, the influences of stomatal behavior (stomatal size, stomatal density, stomatal open and stomatal conductivity) on the photosynthesis and transpiration characteristics of *A. lobophylla* and *A. potaninii* were studied in this paper.

Materials and methods

The study was carried out in the Jinchuan and Markang County of Sichuan Province. *A. lobophylla* population distributes in the Jinchuan County at altitudes from 2 300 m to 3 400 m, and *A. potaninii* population in the Markang County at altitudes from 2 600 m to 3 500 m. They all grow in xerophilous thorny brushwood and sub-alpine conifer-broad-leaves forest. The *A. lobophylla* materials come from sample plots with 5 different altitudes (2 300 m, 2 630 m, 2 720 m, 3 250 m and 3 330 m), while *A. potaninii* from 4 altitudes (2 800 m, 3 010 m, 3 180 m and 3 400 m).

Living leaves were measured by LI-6400 model photosynthesis analysis instrument from 14:00 to 17:00 for studying photosynthesis and transpiration characteristics. 3 samples at each altitude and 3 different parts of each sample were measured. Sample leaves were fixed by 3% glutaraldehyde solution so that the characteristics of stomatal behavior, stomatal density and stomatal open were observed in room and relative data were gained and processed.

Results and discussion

In order to analyze the direct or indirect influence of stomatal behavior (interaction of stomatal behavior) on photosynthesis and transpiration characteristics of *A. lobophylla* and *A. potaninii*, the path coefficient analysis method was introduced. By the method, a correlation coefficient was divided into several parts according to the cause of formation (Zhou 1996; Farquhar 1982; Jiang 1996). The sum of direct path coefficient and indirect path coefficient is correlation coefficient, thus it has not only the characteristics of regression coefficient but also that of correlation coefficient. Because the path coefficient is a relative number without unit, they can be directly compared with each other (Yan 1996; Yan 1997). According to path coefficient analysis, the relationship between stomatal behavior and the photosynthesis and tran-

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spiration characteristics of *A. lobophylla* and *A. potaninii* was analyzed preliminary, meanwhile the influence of stomatal behavior changes at different altitudes on photosynthesis, transpiration and intercellular CO_2 concentration was further studied. Changes of the stomatal behavior at different altitudes and correlation coefficient were shown in Table 1 and Table 2.

Table 1. Stomatal behavior changes at different altitudes

Altitude /m	Stomatal density /individuals•mm^{-2}	Stomatal size /μm	Stomatal open /μm	Stomatal conductivity /mol•m^{-2}•s^{-1}
A. lobophylla				
2 300	110	31.82	7.15	0.029
2 630	149	35.88	8.44	0.015
2 720	142	35.75	7.37	0.024
3 250	174	33.42	7.50	0.058
3 330	123	34.73	8.61	0.026
A. potaninii				
2 800	187	33.48	7.99	0.073
3 010	249	33.40	8.22	0.104
3 180	216	33.40	8.23	0.154
3 400	220	32.38	7.16	0.011

Table 2. Correlation coefficients of stomatal behavior changes

	Stomatal density	Stomatal size	Stomatal open	Stomatal conductivity
A. lobophylla				
Stomatal density	1	0.322 2	0.007 0	0.562 9
Stomatal size		1	0.574 8	-0.505 3
Stomatal open			1	-0.417 1
Stomatal conductivity				1
A. potaninii				
Stomatal density	1	-0.113 2	0.129 7	0.148 3
Stomatal size		1	0.957 3*	0.796 1
Stomatal open			1	0.909 2
Stomatal conductivity				1

Note: *--significant at 0.05 level

Relationship between photosynthesis rate and stomatal behavior at different altitudes

From simple correlation coefficient (Table 3), there is no significant correlation between stomatal behavior and photosynthesis rate for *A. lobophylla* and *A. potaninii* in terms of variation at different altitudes.

Table 3. Correlation coefficient between photosynthesis rate and stomatal behavior

Species	Stomatal density	Stomatal size	Stomatal open	Stomatal conductivity
A. lobophylla	0.744 5	-0.268 3	-0.631 8	0.823 7
A. potaninii	0.049 1	0.304 1	0.464 2	0.789 4

The results of path coefficient analysis (Table 4) indicated that stomatal open and stomatal conductivity significantly influenced the photosynthesis rate of *A. potaninii*. Stomatal size has indirect effect on photosynthesis rate by stomatal open and stomatal conductivity. Compared with *A. potaninii*, photosynthesis rate of *A. lobophylla* is little influenced by stomatal size, stomatal open and stomatal conductivity, except for stomatal density. It is concluded that there is less correlation between photosynthesis of *A. lobophylla* and stomatal factors at different altitudes; on the contrary, its photosynthesis is influenced by non-stomatal factors.

Relationship between transpiration rate and stomatal behavior at different altitudes

From the correlation coefficient analysis (Table 5), the correlation coefficient between stomatal conductivity and transpiration rate of *A. lobophylla* achieves significant level, but that of other stomatal behavior factor does not do. The correlation coefficient between the stomatal open, stomatal conductivity and transpiration of *A. potaninii* is close to significant level. By path coefficient analysis (Table 6) the direct effect

of stomatal open on transpiration rate for *A. potaninii* is more evident, stomatal conductivity has indirect influence. But direct effect of stomatal density on the transpiration rate of *A. lobophylla* is the most significant.

Table 4. Path coefficient analysis between photosynthesis rate and stomatal behavior

	Direct path coefficient	Indirect path coefficient			
		Stomatal density	Stomatal size	Stomatal open	Stomatal conductivity
A. lobophylla					
Stomatal density	0.704 5		-0.042 6	-0.003 5	0.086 2
Stomatal size	-0.132 4	0.227 0		-0.285 5	-0.073 3
Stomatal open	-0.496 8	0.004 9	-0.076 1		-0.063 8
Stomatal conductivity	0.153 1	0.396 6	0.066 9	0.207 2	
A. potaninii					
Stomatal density	0.133 8		-0.104 1	-0.350 0	0.369 3
Stomatal size	0.919 7	-0.015 1		-2.583 7	1.983 2
Stomatal open	-2.698 8	0.017 4	0.880 4		2.655 2
Stomatal conductivity	2.491 3	0.019 8	0.732 1	-2.453 9	

Table 5. Correlation coefficient between transpiration rate and stomatal behavior

Species	Stomatal density	Stomatal size	Stomatal open	Stomatal conductivity
A. lobophylla	0.606 6	-0.550 4	-0.532 2	0.881 3*
A. potaninii	0.450 6	0.779 4	0.926 8	0.924 8

Note: *--significant at 0.05 level

Table 6. Path coefficient analysis between transpiration rate and stomatal behavior

	Direct path coefficient	Indirect path coefficient			
		Stomatal density	Stomatal size	Stomatal open	Stomatal conductivity
A. lobophylla					
Stomatal density	1.011 8		-0.297 0	-0.000 6	-0.107 6
Stomatal size	-0.921 7	0.326 0		-0.051 3	0.096 6
Stomatal open	-0.089 2	0.007 1	-0.529 8		0.079 8
Stomatal conductivity	-0.191 2	0.569 5	0.465 7	0.037 2	
A. potaninii					
Stomatal density	0.267 9		0.027 3	0.107 5	0.048 0
Stomatal size	-0.241 1	-0.030 3		0.793 1	0.257 7
Stomatal open	0.828 5	0.034 7	-0.230 9		0.294 4
Stomatal conductivity	0.323 8	0.037 9	-0.192 0	0.753 3	

Relationship between intercellular CO_2 concentration and stomatal behavior at different altitudes

There is little correlation coefficient between stomatal behavior and intercellular CO_2 concentration for *A. lobophylla* and *A. potaninii* (Table 7). Analysis result of path coefficient (Table 8) showed that the influence of stomatal open on intercellular CO_2 concentration of *A. potaninii* was the most significant, while stomatal size had indirect effects on intercellular CO_2 concentration nearly equal to that of the direct effect. In terms of intercellular CO_2 concentration changes of *A. lobophylla* with altitude chang, stomatal open also has the more direct effect. Generally, stomatal open, stomatal conductivity and stomatal size affect intercellular CO_2 concentration of *A. potaninii* , while for *A. lobophylla* it is only stomatal open to have influence on the intercellular CO_2 concentration.

Table 7. Correlation coefficient between intercellular CO_2 concentration and stomatal behavior

Species	Stomatal density	Stomatal size	Stomatal open	Stomatal conductivity
A. lobophylla	-0.593 1	0.132 5	0.779 5	-0.533 8
A. potaninii	0.205 0	0.752 0	0.694 9	0.340 8

Table 8. Path coefficient analysis between intercellular CO_2 concentration and stomatal behavior

	Direct path coefficient	Indirect path coefficient			
		Stomatal density	Stomatal size	Stomatal open	Stomatal conductivity
A. lobophylla					
Stomatal density	-0.695 3		-0.019 3	0.006 3	0.115 1
Stomatal size	-0.059 8	-0.224 0		0.519 6	-0.103 3
Stomatal open	0.904 0	-0.004 9	-0.033 4		-0.085 3
Stomatal conductivity	0.204 5	-0.391 4	0.030 2	-0.377 1	
A. potaninii					
Stomatal density	-0.154 0		0.159 6	0.534 1	-0.334 8
Stomatal size	-1.410 2	0.017 4		3.942 4	-1.797 6
Stomatal open	4.118 1	-0.020 0	-1.350 0		-2.053 3
Stomatal conductivity	-2.258 2	-0.022 8	-1.122 6	3.744 4	

Conclusions

There is not significant correlation between the measured stomatal behavior and photosynthesis and transpiration characteristics of *A. lobophylla*. Meanwhile, there is little consistency among stomatal behavior factors that have a great influence on photosynthesis and transpiration characteristics of *A. lobophylla*. On the other hand, stomatal open, stomatal conductivity and stomatal size have a great influence on changes of photosynthesis and transpiration characteristics of *A. potaninii* at different altitudes. This indicates that the photosynthesis and transpiration characteristics of *A. potaninii* closely relate to its life rhythm, and are strongly restricted by stomatal behavior. However, stomatal behavior has less influence on photosynthesis and transpiration of *A. lobophylla* at different altitudes, which indicated the photosynthesis and transpiration characteristics of *A. lobophylla* were easy to be influenced by environment factors. When environmental condition is not suited for growing, it is hard to complete normal photosynthesis and transpiration function by stomatal behavior readjustment.

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